

Time Reversal in Metamaterials and Photonic Crystals

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The conventional route to time reversal of light pulses is via 4-wave mixing. Two counter propagating beams,

$$\mathbf{k}_1 = +\mathbf{k}, \omega_1 = \omega, \quad \mathbf{k}_2 = -\mathbf{k}, \omega_2 = \omega$$

interact with the signal, \mathbf{k}_3, ω , via a non-linear medium to produce a time reversed signal. One slightly unconventional view is to interpret the process as the signal making a vertical $\Delta\mathbf{k} = 0$ transition between $+\omega$ and $-\omega$. Since the frequency appears in the field equations as ωt , this equivalent to reversing the time.

This interpretation suggests another route to time reversal which is to make a spatially uniform perturbation in the dielectric function of the material through which the pulse is propagating, but with the perturbation confined to a very short time interval.

$$\varepsilon(t) = \varepsilon_{static} + \eta \delta(t - t_0)$$

The perturbation contains all frequency components, but spatial uniformity forbids anything but a \mathbf{k} -conserving transition. In a uniform medium this means a transition from $+\omega$ to $-\omega$ thus producing a time reversed signal.

In practice generating such a rapidly change in the dielectric function is impracticable at optical frequencies as the time scale has to be less than $1/\omega$. However in metamaterials and photonic crystals the dispersion relationships are much richer and we shall show how it is possible to effect time reversal using perturbations on a time scale much larger than $1/\omega$ giving new opportunities for the time reversal of pulses ranging from RF to the visible in frequency.